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Abstract (300 words max, currently 282)

Prioritising the management of invasive alien species (IAS) is of global importance and within Europe integral to the EU IAS regulation. To prioritise management effectively the risks posed by IAS need to be assessed, but so too does the feasibility of their management. While risk of IAS to the EU has been assessed, the feasibility of management has not.

We assessed the feasibility of eradicating 60 new (not yet established) and 35 emerging (established with limited distribution) species that pose a threat to the EU, as identified by horizon scanning. The assessment was carried out by 34 experts in invasion management from across Europe, applying the Non-Native Risk Management scheme to defined invasion scenarios and eradication strategies for each species, assessing the feasibility of eradication using seven key risk management criteria. Management priorities were identified by combining scores for risk (derived from horizon scanning) and feasibility of eradication.

The results show eradication feasibility score and risk score were not correlated, indicating that risk management evaluates different information than risk assessment. Seventeen new species were identified as particularly high priorities for eradication should they establish in the future, while fourteen emerging species were identified as priorities for eradication now.

A number of species considered highest priority for eradication were terrestrial vertebrates, a group that has been the focus of a number of eradication attempts in the EU. However, eradication priorities also included a diverse range of other taxa (plants, invertebrates and fish) suggesting there is scope to broaden the taxonomic range of attempted eradication in the EU.

We demonstrate that broad scale structured assessments of management feasibility can help prioritise IAS for management. Such frameworks are needed to support evidence based decision making.

Introduction

Managing the increasing risks and impacts of invasive alien species (IAS, cf invasive non-native, invasive non-indigenous species) is one of the great societal challenges of the 21st century (Seebens *et al.*, 2018, Simberloff *et al.*, 2013, Vilà *et al.*, 2011). Ambitious international goals aim to reduce or halt these rising impacts, including Aichi Target 9 of the Convention on Biological Diversity (CBD, 2014), which commits signatories to control or eradicate priority species. This commitment is reflected in European Union (EU) regulation 1143/2014 on IAS (EU, 2014). However, the control or eradication of IAS can be expensive; with numerous species and limited resources, decision makers must carefully prioritise which species to manage and how (McGeoch *et al.*, 2016).

Risk assessment, the process by which the likelihood and magnitude of impact is assessed, is commonly used to support the prioritisation of IAS and has been well used in the EU and elsewhere (Roy *et al.*, 2018b). However, simply assessing the risks and impacts of IAS is of limited use for prioritising their management, as it fails to take into account the feasibility of delivering an effective response (Booy *et al.*, 2017). Failure to account for management feasibility can result in species being prioritised that may be unmanageable or for which management is unlikely to be economically viable (Branquart *et al.*, 2016, Cassey *et al.*, 2018, Courtois *et al.*, 2018). As a result resources could be wasted or used inefficiently and confidence in decision making could be reduced.

A number of approaches are available to support the assessment of IAS management feasibility, its costs and benefits. Economic cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA) have been used to assess aspects of management for particular species and in some cases to approve management schemes prior to implementation (Blackwood *et al.*, 2010, Born *et al.*, 2005, Courtois *et al.*, 2018). However, purely economic CBA and CEA approaches generally require large quantities of empirical information, are costly and time-consuming to produce (Reyns *et al.*, 2018). There are also complexities in how to effectively monetise the full range of social, environmental, animal welfare and biodiversity consequences of IAS management (Hoagland & Jin, 2006). As a result, CBA and CEA are generally applied to individual IAS and particular situations (Panzacchi *et al.*, 2007, Rajmis *et al.*, 2016), but are difficult to apply across large numbers of different species to identify broad management priorities.

Multi-criteria approaches (Born *et al.*, 2005), including Multi Criteria Decision Analysis (MCDA), provide a means of assessing and comparing between larger numbers of species using available data against a wide range of different criteria, without the need for monetisation. As such, they are commonly used to support risk assessment, as well as risk management in some cases (EPPO, 2011, OiE, 2017, Mehta *et al.*, 2010). One such approach is the Non-Native Risk Management (NNRM) scheme (Booy *et al.*, 2017), which uses multiple criteria relevant to decision makers (beyond solely monetary considerations) to score different aspects of IAS management, based on pre-defined invasion scenarios and strategies. Within this scheme, species are assessed using expert judgement and elicitation methods, incorporating empirical information where available and including a framework for assessing confidence. This approach is similar to methods used for IAS risk assessment (Baker *et al.*, 2008, Brunel *et al.*, 2010, Copp *et al.*, 2016, Essl *et al.*, 2011, Mumford *et al.*, 2010, Vanderhoeven *et al.*, 2017) and increasingly throughout the field of ecological conservation (Adem Esmail & Geneletti, 2018, Burgman *et al.*, 2011).

To date, the NNRM has been applied at regional (Osunkoya *et al.*, 2019) and national scales (Booy (Adriaens *et al.*, 2019, Booy *et al.*, 2017); however, there are advantages of applying it at larger scales. IAS pose threats to multiple countries and do not respect national boundaries, meaning that management responses will often require cooperation and resource sharing between states to be effective (Robertson et al 2015). Large-scale prioritisation is currently of particular relevance in the EU to support the implementation of the Regulation 1143/2014 on the prevention and management of the introduction and spread of IAS.

Here we apply the NNRM at a large scale to evaluate an existing multi-taxa list of new and emerging IAS that threaten the EU as identified by horizon scanning (Roy *et al.*, 2015, Roy *et al.*, 2018a). We use this evaluation of species along with existing risk assessment scores (derived from horizon scanning) to consider potential priorities for management within the EU. In particular, we consider priorities for (i) early detection and rapid eradication of new species should they start to establish in the EU; and, (ii) eradication of species that are currently established in the EU, but with limited distributions. In addition, we provide an insight into potential priorities for (iii) prevention and (iv) long-term management. We explore the suitability of using this approach for large scale prioritisation and consider patterns in the feasibility of eradication in different environments and at different scales.

Methods

A list of 95 species were used that were identified as high or very high risk through the horizon scanning by (Roy *et al.*, 2015). This comprised terrestrial, freshwater and marine taxa that were categorised as either new to the EU (i.e. not yet established) or emerging (i.e. established with limited distributions) (Table 5.1). For each species, a risk management assessment was completed using a modified version of the Non-Native Risk Management (NNRM) scheme (Booy *et al.*, 2017). Modifications included standardising invasion scenarios based on the number of discrete populations and total combined area of all populations (Supplementary Information 1). This helped take into account the greater complexity of assessment at the EU scale and also allowed for patterns in feasibility of eradication at increasing area and number of populations to be analysed. Species were included that had a range of areas and populations (Table 5.2). However, as the focus of horizon scanning was on new and emerging species, most were at the low end of the scale (i.e. 1-3 populations covering less than 1ha in total). The full, modified scheme and guidance is available (Supplementary Information 1).

A combination of expert elicitation, review and consensus building methods were used to produce and validate risk management assessments following similar approaches to (Roy *et al.*, 2014) and (Booy *et al.*, 2017). In total, 34 experts were engaged in the elicitation process grouped into five taxonomic specialisms: freshwater animals, terrestrial vertebrates, terrestrial invertebrates, marine species, and plants (excluding marine plants). Each group comprised 5-8 experts chosen by the organisers in cooperation with an appointed group leader based on proven experience of IAS management and representation of a range of EU member states. Each species was independently assessed by at least three different experts.

Risk management assessments were first drafted by expert groups using the NNRM template. The invasion scenario (a factual description of the current or potential distribution and spread of the species in the EU) and eradication strategy (a realistic combination of methods and techniques for eradication) for each species was completed by the group leader, in consultation with other experts in their group as necessary. For emerging species the scenario was the current distribution of the species in the risk management area. For new species, the most likely invasion scenario was used, based on the likely extent of the species at the point of detection in the wild in the risk management area given current surveillance. Each species was then assessed independently by at least three different experts from each group, who provided response and confidence scores for seven risk management components (i.e. effectiveness, practicality, cost, impact, acceptability, window of opportunity and likelihood of reintroduction) as well as scoring the overall feasibility of eradication. These were collated, anonymised and the scores returned to the expert group, along with the median response and confidence scores for each risk management component and the overall feasibility of eradication.

A two-day workshop (17-18 May 2016) was held to review, refine and ultimately agree scores by consensus. Twenty-eight of the original experts, including all group leaders, attended. The first session was for group leaders only and aimed to reduce linguistic uncertainty with regards to feasibility criteria and scoring ranges, as well as clarifying the requirements of the rest of the workshop. To aid in this, each group leader presented their group's initial scores, discussed any areas of potential ambiguity and agreed on clarifications. This was then repeated in plenary so participants went through the scoring guidance with the organisers to resolve ensure consistency in application. The main workshop proceeded with a simplified, facilitated Delphi approach (Mukherjee *et al.*, 2015) including two rounds of consensus, within and across expert groups:

1. Group leaders presented an overview of the initial scores from their groups to all participants, who were encouraged to discuss and challenge the scores.

2. Expert groups reviewed and refined the scores of their group, taking into account the discussions from session 1. Each group was provided with the median response and confidence scores for each of their species and asked to discuss disagreement on scores and refine them where necessary.

3. The final stage of the scoring process was to build consensus of all participants on the refined scores across all groups. Scores were collated and presented back in plenary by two facilitators (OB and PG), focussing on reaching consensus on the final overall feasibility of eradication score for each species. Participants were encouraged to discuss and challenge the scores of other groups with any changes at this point made with the consensus of the whole group.

Analysis

Risk Management Scores

We assessed the interrelation between the seven management components scores and the overall feasibility of eradication score in ordinal space using a factor plot and non-metric multi-dimensional scaling. A distance matrix of species by component was analysed using the *isoMDS* function in the MASS (Venables & Ripley, 2002) package and then visualised using FactoMineR package (Le *et al.*, 2008), colouring each species by the independent overall score. Underlying patterns of correlation between components (variables) were visualised in a factor plot.

Polychoric correlations (function polycor from polychor package (Fox, 2019) were used to compare the ordinal scores for overall risk (derived from horizon scanning) and the overall feasibility of eradication scores (derived from this exercise). Correlation between the two assessments implies they measure similar underlying information; we did not expect to find strong correlation.

Effect of extent and environment on overall feasibility

To assess the relationship between the score for overall feasibility of eradication (ordinal response) and environment (terrestrial, freshwater, marine), total area and number of populations, a cumulative link model (CLM) was fitted using the R package 'Ordinal' (Christensen, 2018). It was hypothesised that the overall feasibility of eradication score for each species would decline with increasing spatial extent (total area and number of populations) and be dependent on the environment in which the species occurred. Population categories 'C' and 'D' were pooled into one category (10+ populations) as were areas >10Ha (greater than category 3) owing to sparse data at these ranges. Ordinal regression assumes proportional odds (i.e. the relationship between each pair of outcome groups is the same). Statistical tests for proportional odds have been criticised as they tend to falsely reject the null hypothesis, so proportionality was assessed using a graphical method following Bender and Grouven (1997) and Gould (2000). This method uses plots of predicted values derived from a series of binary logistic regressions to check the assumption that coefficients are equally separated across cut-points.

The final model was used to predict the feasibility of eradication for every combination of environment, total area and number of populations. Model predictions were expressed as the probability of the overall feasibility of eradication score being each of the five response levels (very high to very low) and visualised using ggplot2 (Wickham, 2009).

Prioritisation

To indicate priorities for eradication, we combined the overall risk assessment scores (derived from horizon scanning (Roy *et al.*, 2015)) with the overall feasibility of eradication scores (from this risk management exercise) in a prioritisation matrix (following Booy *et al.*, 2017). As both the overall risk and overall feasibility of eradication scores used a five-point scale (very low to very high) the result was a 5x5 prioritisation matrix, with priorities ranging from lowest (1:1) to highest (5:5) (Table 3). However, as only species with risk assessment scores of high and very high were included in this exercise, only positions in the top two rows of the matrix could be achieved, resulting in priorities ranging from medium-low (4:1) to highest (5:5).

The matrix was also used to investigate other priorities, including prevention and long-term management. For new species, prevention was likely to be a particular priority if the species posed a high risk and the feasibility of eradication after arrival was low. For emerging species, long-term management (e.g. containment, slowing spread, control) was likely to be a particular priority if the species posed a high risk and the feasibility of eradication was low. These priorities corresponded to the top left corner of the matrix and are marked: ++ highest, and + high priority for prevention / long-term management (Table 3).

Results

Risk Management scores

The workshop resulted in consensus risk management scores for all species.

Scores for overall risk (derived from horizon scanning) and overall feasibility of eradication (derived from this exercise) were not correlated: polychoric correlation, rho = -0.281 +/- s.e. 0.136, Chi sq =0.519, p=0.89 (note rho is the test statistic where values near 0 indicate little agreement).

The scores for overall feasibility of eradication aligned in sequence with the individual component scores (i.e. effectiveness, practicality, cost, impact, acceptability, window of opportunity and likelihood of reinvasion) with some overlap (Supplementary Information 2). This suggests that while component scores were in general agreement with the overall score it was not possible to consistently determine the overall score based on individual components. Five of the risk management components (effectiveness, practicality, cost, impact and acceptability) were correlated with overall feasibility of eradication, while window of opportunity and likelihood of reinvasion were not (Supplementary Information 3).

Effect of extent and environment on the overall feasibility of eradication

The assumptions of proportionality were met for the cumulative link model as the thresholds (intercepts) for each covariate were broadly similar distances apart (Supplementary Information 4). All variables (environment, total area and number of populations) were significant predictors of the scores for overall feasibility of eradication (Supplementary Information 5).

In general, the scores for overall feasibility of eradication were lowest for marine species and highest for terrestrial species, with freshwater species in between (Supplementary Information 5). In each environment, overall feasibility of eradication decreased as total area occupied or number of populations of the IAS increased (Supplementary Information 5).

Increasing total area and number of populations reduced the probability of very high and high scores for overall feasibility of eradication in all environments (Fig 1). For terrestrial species, high overall scores for feasibility of eradication were more probable than low scores at every combination of total area and number of population. In the freshwater environment, high scores were probable when either the total area was small (<1ha) or there were few populations (<1-3), but beyond this low scores were more probable. For marine species, low scores were more probable than high scores at all combinations.

Prioritisation

Combining scores for overall risk (derived from horizon scanning) and overall feasibility of eradication resulted in six levels of eradication priority: highest (1 species), very high (20), high (36), med-high (20), medium (14) and med-low (4) (Fig 2). These were further divided into priorities for future rapid eradication of new species should they establish (Fig 2a) and eradication priorities for emerging species that are already established (Fig 2b). In addition, new (i.e. not yet established) species for which overall feasibility of eradication on detection was low were considered priorities for prevention (Supplementary Information 6). While, emerging (i.e. already established) species with low feasibility of eradication were considered priorities for long term management (e.g. control, slowing spread, containment) (Supplementary Information 7). Detail on key eradication priorities is provided below and in Tables 4 and 5 (scores for all species are available in Supplementary Information 6 and 7).

Priorities for future rapid eradication of new species

Of the 60 new species, *Orconectes rusticus* (rusty crayfish) scored the highest priority for eradication, with both the overall risk and overall feasibility of eradication scoring very high (Table 4, Fig 2a).

A further 16 species not yet established in the EU were assessed as very high priority for eradication, based on the most likely scenario at the point of detection: seven freshwater fish, three terrestrial plants, three insects, two mammals and one reptile (Table 4, Fig 2a). The invasion scenarios for these species suggested that the majority were likely to be in 1-3 populations covering <1 ha or 1-10 ha at the point of detection. However, two species were considered likely to be in more than 1-3 populations (Asian needle ant, *Pachycondyla chinensis*; and Nile tilapia, *Oreochromis niloticus*) and three were likely to cover 1-10 km^2 (American bison, *Bison bison*; brushtail possum, *Trichosurus vulpecula*; and *L. getula*). The bioregions that species could invade included the Mediterranean (13), Macaronesia (12), Atlantic (8), Continental (7) and Steppic (6) bioregion.

Approximately twelve different methods of eradication were identified for these 16 species, including: shooting, trapping, manual destruction, mechanical removal, herbicide, electrofishing, fyke netting, piscicide, draining, angling, poison baiting and insecticide. The total estimated cost of eradicating all 16 species was in the region of €0.5-2.6M (based on the sum of lower and upper bounds for the risk management component cost). No significant (at the scale of the EU) adverse non-target impacts of management were considered likely. All eradications of these new species had high or very high acceptability, except for *Gambusia affinis* (western mosquitofish) which scored moderate because of potential negative reaction to the use of piscicides. The Window of opportunity for most species was short (2 m-1 year) with two species <2 m, six species 1-3 years and one species (*B. bison*) 4-10 years.

Priorities for eradication of currently established emerging species

Of the 35 emerging species assessed, four were identified as very high priority for eradication and a further ten were identified as high priority (Table 5, Fig 2b).

The top four priority species were terrestrial vertebrates with very high scores for overall risk and high scores for overall feasibility of eradication. The invasion scenario for these species (based on current understanding of the situation in the EU at the time of assessment) suggested that they were established in no more than 3 populations, covering a minimum area of 1ha and maximum area of 100km^2 each. However, there was uncertainty about the status and extent of three of the four species (common myna, *Acridotheres tristis*, Berber toad, *Bufo mauritanicus* and red-vented bulbul, *Pycnonotus cafer*). Current populations of all four species were thought to be limited to Spain, except one population of *A. tristis* in Portugal. The estimated cost of eradicating each species ranged from very low (€1-50k) (*B. mauritanicus*) to moderate (€0.2-1M) (*A. tristis* and coati, *Nasua nasua*), with the total cost of eradicating all four species estimated to range between €0.45-2.25M (based on the sum of lower and upper bounds for the risk management component cost). The key eradication methods identified included netting, trapping, manual capture and shooting, which were not considered to cause significant adverse environmental, social or economic harm. Acceptability scores were high, except for *N. nasua*, which scored medium. The window of opportunity for all of these species was 1-3 years.

The ten high priority established species comprised three terrestrial plants, one freshwater plant, two terrestrial vertebrates, two freshwater animals, one insect and one marine tunicate (Table 5). These included species with primarily high overall risk and high overall feasibility of eradication scores; however, two species scored very high risk with only medium feasibility (alligator weed, *Alternanthera philoxeroides*; and the marine tunicate, *Botrylloides giganteum*). Invasion scenarios suggested that the majority of high priority species were relatively well confined comprising 1-3 populations, although three plants had more (10-50 populations) as did the oriental weather-fish, *Misgurnus anguillicaudatus* (10-50 populations) and the apple tree-borer, *Saperda candida* (4-10 populations). The area covered by these species was thought to range from <1 ha (common yabby, *Cherax destructor*; and *B. giganteum*) to >100 km^2 (Indian spotted deer, *Axis axis*) and they were present in seven EU Member States, including: Italy (3), France (3), Germany (3), Spain (2), Croatia (1), United Kingdom (1) and Netherlands (1). The cost range for eradicating all ten species was in the region of €1M-5.5M. Barriers to eradication were identified for some species. For example, the eradication of *M. anguillicaudatus* using electrofishing, fyke netting and piscicide was considered likely to cause moderate adverse environmental harm as well as low Acceptability. Both *Rhea americana* (greater rhea) and *A. axis* received only medium Acceptability scores; while the removal of *Ligustrum sinense* (Chinese privet) using mechanical means and herbicide had the potential to cause adverse environmental impacts. The window of opportunity for all of the ten high priority species was 1-3 years, except *B. giganteum* which had a very short Window of Opportunity (<2 months) and *A. axis* with a longer window (4-10 years).

Prevention and long term management priorities

Where a species that has not yet established poses a high overall risk, but overall feasibility of eradication on detection is low, it is likely to be a priority for prevention. Three species were identified as particularly important for prevention based on very high overall risk and low or very low scores for overall feasibility of eradication: *Plotosus lineatus* (striped eel catfish), *Homarus americanus* (American lobster) and *Codium parvulum* (a green algae) (Fig 2a; Supplementary Information 6).

For already established species with low scores for overall feasibility of eradication, long term management (e.g. containment, slowing spread, control) may be a high priority. Eleven species were identified as potentially high priorities for long term management on this basis (Fig 2b; Supplementary Information 7). Three scored very high overall risk and very low overall feasibility of eradication, including *Arthurdendyus triangulatus* (New Zealand flatworm), *Pterois miles* (lion fish) and *Penaeus aztecus* (northern brown shrimp). The remaining eight species scored high overall risk and very low overall feasibility of eradication or very high overall risk and low overall feasibility, including: two marine invertebrates (a hydroid, *Macrorhynchia philippina*; and a polychaete, *Pseudonereis anomala*), three freshwater invertebrates (Chinese mystery snail, *Bellamya chinensis*; golden apple snail, *Pomacea canaliculata*; and giant apple snail, *Pomacea maculata*), one terrestrial invertebrate (a parasitic nematode, *Ashworthius sidemi*) and two terrestrial vertebrates (Finlaysons squirrel, *Callosciurus finlaysonii*; and small Asian mongoose, *Herpestes auropunctatus*).

Discussion

We identified priorities for the eradication of new and emerging IAS in the EU using a structured risk management tool combined with risk assessment scores derived from horizon scanning. This exercise not only indicated priorities for the eradication of emerging species and contingency planning for new species, but potential priorities for prevention and long term management as well. While the NNRM has previously been applied at regional and national scales (Adriaens *et al.*, 2019, Booy *et al.*, 2017, Osunkoya *et al.*, 2019), this is the first application across multiple countries. Despite increased complexity at this scale and a lack of information on the status of some species in the EU, we found that the scheme could be applied successfully at a continental scale.

Although the species-specific eradication feasibility scores resulting from this exercise provide support for those taking decisions about how and which IAS to manage, they are not straightforward management recommendations. The feasibility scores are linked to specific invasion scenarios and eradication strategies, which are subject to knowledge gaps and change, for example as a result of changes in species distributions and new eradication methods becoming technically or legally available. Also, often adaptive management can be applied which takes into account inherent uncertainty of management outcomes (Gregory *et al.*, 2012, Richardson *et al.*, 2020).

As with other screening methods (including horizon scanning, rapid risk assessment and hazard identification), the results should be considered preliminary and subject to further in-depth assessment. For example, detailed management plans would need to be drafted to implement the management priorities identified here and these should include further assessment in the field to confirm population sizes and distribution as well as the applicability of management methods. These need to accommodate for alternative strategies if eradication actions do not obtain the expected result. Careful planning is necessary to evaluate the effort needed for eradication, which can be supported by modelling (e.g. Tattoni *et al.*, 2006).

Although the assessment presented here provides insight into prevention and long term management priorities, this is not the focus of the exercise. Tools for further in-depth assessment based on the initial priorities identified here could include the use of cost-benefit analysis, cost-effectiveness analysis and eradication probability modelling (Drolet *et al.*, 2015).

We assessed high and very high risk IAS identified by horizon scanning as these are likely candidates for prevention, early detection and rapid eradication given their absence or limited status in the EU (Roy *et al.*, 2015). They are also of particular concern currently in the EU which has recently adopted regulation 1143/2014 on IAS that emphasises the importance of prevention and rapid eradication (EU, 2014). While horizon scanning provides a useful method for reducing long lists of potentially thousands of species to a shorter list of those most likely to be threats (Roy *et al.*, 2015), it is of limited use for prioritising specific actions as it does not take into account the feasibility of management (Booy *et al.*, 2017, Vanderhoeven *et al.*, 2017). By applying risk management criteria, our study refined this list into specific management priorities, aligning with the guiding three step hierarchical approach of IAS management set out in the Convention on Biological Diversity (UNEP, 2011).

The results of this study demonstrate the value of incorporating both risk assessment (here derived from horizon scanning) and risk management criteria when prioritising IAS. There was no correlation between risk management and risk assessment scores, indicating that risk management evaluates information that is different to risk assessment. This additional information is an essential part of risk analysis, and fundamental to decision-makers, who must take into account a wide range of criteria that go beyond risk (Dana *et al.*, 2014, Kerr *et al.*, 2016, Simberloff, 2003). While risk management is traditionally included along with risk assessment as part of an overall approach to risk analysis in other disciplines, such as plant health, animal health and food safety (EFSA, 2010, OiE, 2017, Ahl *et al.*, 1993, FAO, 2013) it has rarely been applied so systematically to IAS. This is particularly true in the EU, where risk assessment alone has been the dominant method used to support prioritisation (Essl *et al.*, 2011, Heikkilä, 2011, Kerr *et al.*, 2016, Roy *et al.*, 2018b, Turbé *et al.*, 2017, Vanderhoeven *et al.*, 2017). Our results highlight the importance of incorporating this step and, by doing so, identifying refined priorities more specifically linked to management outcomes.

The standardization of invasion scenarios based on the number of discrete populations and total combined area of all populations, a modifications of the NNRM scheme, allowed us to explore the relationship between invasion scenarios and the feasibility of eradication at different spatial scales. Across all environments the overall feasibility of eradication decreased as extent increased, which reflects the fact that elements of feasibility, such as cost and resource effort, are known to scale with extent (Brockerhoff *et al.*, 2010, Howald *et al.*, 2007, Rejmánek & Pitcairn, 2002, Robertson *et al.*, 2017).

Terrestrial species received highest scores for overall feasibility of eradication, followed by freshwater species and then marine species, which reflects the different challenges of eradication in these different environments (Booy *et al.*, 2017). While the feasibility of eradicating terrestrial species was highest at smaller scales, it remained likely even at larger scales, albeit with reduced confidence. Indeed, successful eradications on large land masses have been reported in the EU of invasive mammals and birds (Robertson *et al.*, 2015, Robertson *et al.*, 2017). In contrast, the feasibility of eradicating freshwater species was likely to be feasible at small scales (i.e. few populations <1-3, or small area <1ha), but unlikely to be feasible at larger scales (i.e. > 1-3 populations and >1ha). In the marine environment, feasibility was likely to be low, even at small extents. These results indicate that extent alone is not a good predictor of feasibility when comparing species from different environments. They also suggest that early detection and rapid eradication is particularly important for freshwater species, for which action at an early stage of invasion considerably increases the likelihood that eradication will be feasible. This appears to be less important for terrestrial species, for which eradication remains feasible across considerably larger scales, and for marine species, for which eradication even at small scales is unlikely to be feasible in most circumstances. Of course, eradication is not the only rapid response measure that could be deployed, and these results do not preclude the possibility that early detection and rapid action to contain or slow the spread of a marine species may be useful.

We identified four species already established in the EU (i.e. emerging) as highest priorities for eradication: common myna, *Acridotheres tristis*; Berber toad, *Bufo mauritanicus*; coati, *Nasua*

nasua; red-vented bulbul, *Pycnonotus cafer*. These are all terrestrial vertebrates with small population sizes and small areas, which reflects experience from the EU and elsewhere, where eradication campaigns have often targeted terrestrial vertebrates in small areas (Genovesi, 2005, Mayol *et al.*, 2009, Saavedra, 2010) and sometimes across wider extents (Robertson *et al.*, 2017). However, the next ten priorities represented a much wider range of taxa including plants, invertebrates and fish, suggesting there may be scope to widen the taxonomic range of attempted eradications in the EU. Our results indicate that eradication is not only feasible for the top fourteen species, but could be relatively inexpensive (total cost estimate to eradicate the top four established priority species with limited distributions in the EU was €0.45-2.25M, while total cost for the next ten species was €1-5.5M) in comparison to EU funding for other IAS projects (Scalera, 2009). However, although cost is a very important factor in the overall feasibility of eradication (Booy *et al.*, 2017), costing eradications is complex and comprehensive data on the cost of invasive species eradications are generally scarce (Adriaens *et al.*, 2015, Donlan & Wilcox, 2007) which warrants interpreting these crude ordinal cost estimates with caution. Also, the cost is very dependent on the specific invasion scenarios and management strategies drafted for this exercise. As the invasion extent of several species appeared poorly documented (e.g. *A. tristis*) or surrounded by considerable uncertainty (e.g. *B. mauritanicus*), costs could have been underestimated. Lastly, the extent of a species invasion can rapidly change. On the other hand, the cost for eradication could also be reduced by managing several co-occurring species with similar management approaches at once (Mill *et al.*, 2020). Such concrete, practical cost estimates are beyond the broad scale feasibility assessment performed in our study.

Lower scores for some risk management components suggest potential barriers to eradication that would need to be overcome. These include the medium acceptability scores for eradicating the *N. nasua* (coati), *A. axis* (Indian spotted deer) and *R. americana* (greater rhea), which indicates a potential lack of public or stakeholder acceptance for this work on perceived animal welfare grounds. While acceptance of the use of herbicides can be a barrier to eradicating invasive non-native plants, this was not considered a significant problem for the plants included in the high priority lists. However, acceptability was a potential barrier for the eradication of *M. anguillicaudatus* (oriental weatherfish) because of potential public concern over the use of piscicides. Furthermore, the use of piscicides in public waters is prone to meet legal barriers in most EU countries which is reflected in medium scores for practicality. Gaining access is a potential barrier to the eradication of some plant species, especially where they grow in difficult terrain. This was the case for *Euonymus fortunei,* which received a low practicality score because the most likely invasion scenario included the potential for its establishment on cliff edges. While these barriers are challenging and would have to be addressed as part of an eradication strategy, they were not considered insurmountable by the assessors.

Of the new (i.e. not yet established) species assessed, 43 were identified as potential priorities for eradication on arrival, although 17 were particularly high priority (highest and very high). Different priority species could establish in almost any region of the EU and would require a quick (<1 year) response to ensure the response was effective and reduce cost in the long term. Response teams would need to be capable of using a wide range of management techniques, with 13 broad eradication techniques identified for the top 17 high priority species. Indeed, for rapid eradication of new IAS in the EU to be effective, our results indicate coordination across Member States would be key to encourage the development and timely deployment of the plans. This would require Member States to agree on priority species and to maintain access to response teams with a broad range of management expertise and capacity, which may be lacking in some cases. Contingency planning may help to address these issues and can help ensure rapid eradication is delivered effectively and efficiently, by agreeing in advance the roles, responsibilities and resources that will be used to respond to a new incursion before it happens. The priority species identified here would be good candidates for EU wide IAS contingency planning.

While the main role of the NNRM is to identify priorities for eradication and contingency planning, it also identifies potential priorities for long-term management and prevention. Long term management is likely to be a priority for established species where the overall feasibility of eradication is low and the overall risk is high. For example, *Arthurdendyus triangulatus* (New Zealand flatworm) for which the feasibility of eradication from its current EU distribution was considered very low, but for which slowing its spread, perhaps through phytosanitary measures, may be feasible (Boag & Yeates, 2001). Similarly, the NNRM can identify potential prevention priorities for species that are not yet established where the feasibility of eradication is low and the risk high. For example, should *Homarus americanus* establish in EU waters it is unlikely that eradication would be feasible and so prevention, perhaps by tightening control of its release and escape pathways (Jørstad *et al.*, 2011, van der Meeren *et al.*, 2016), should be considered a particularly high priority.

A limitation of the NNRM is that it does not currently evaluate the effectiveness of long-term management (e.g. containment, slowing spread, control) or prevention measures. This is important because long-term management may not always be feasible for species that cannot be eradicated, for example it seems unlikely that long-term management would have much lasting impact on the spreading population of *Pterois miles* (lion fish), despite calls for its consideration (Kletou *et al.*, 2016). Similarly, prevention may not always be feasible, as is likely to be the case for *Plotosus lineatus* (striped eel catfish) which seems set to establish in EU waters following its arrival through the Suez Canal (Edelist *et al.*, 2012). Where considering future prevention and long-term management priorities these factors need to be taken into account and this is a priority for further development of the NNRM.

The approach to prioritisation presented here has application for IAS policy and management. Our results help focus more attention on the eradication of species with limited distributions and contingency planning for new arrivals where this is feasible. The availability of management methods, expected environmental non-target effects and the proportionality of the benefits and costs of eradication are important elements in the current decision making on IAS management in Europe (EU, 2014). These elements of risk management are considered in our assessment and cannot be provided by risk assessment alone. Our approach thus helps to address these, including providing a method to assess the feasibility of eradication, supporting the development of management plans and evaluating the potential benefits of listing.

To date, there is no agreed method for determining whether eradication is feasible and so application is likely to be subjective and potentially inconsistent across the EU. Listing alone may not be sufficient to drive EU wide eradication and contingency planning for species identified as priorities. Other mechanisms may be needed to do this, for example specific eradication and contingency planning programmes under the EU LIFE funding stream. Such programmes would need to be coordinated across the EU and would benefit from sharing of expertise. While our results are focused on the European situation, the procedure here developed could be used in other part of the world to implement or improve strategies to limit the impact of IAS.

As numbers of IAS are predicted to increase and global management targets become more ambitious, transparent methods for prioritising action are essential. We recommend that systematic risk management methods, such as the NNRM, be applied routinely to IAS, as is commonplace in other biosecurity areas. While there are increasing calls for the application of risk assessment to more species (Carboneras *et al.*, 2018), we also suggest that there should be at least as great a focus on risk management in a future with increasingly limited resources for nature conservation.

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Table 1. Count of species by environment, establishment status in the EU and broad taxonomic group

Environment	Status	Plant	Vert	Invert	∑
Freshwater	Established	1	3	5	9
	Not established	0	10	4	14
Terrestrial	Established	6	10	4	20
	Not established	17	11	9	37
Marine	Established	0	1	5	6
	Not established	2	1	6	9
∑		26	36	33	

Table 2. Count of species by scenario code for extent.Letters A-D represent the number of discrete populations (respectively 1-3, 4-10, 10-50, +50) and numbers 1-6 represent total combined area (respectively <1ha, 1-10ha, 10ha-1km2, 1-10km2, 10-100km2, >100km2). For example, the code B2 indicate a species with 4-10 populations covering a total area 1-10ha. For new species (not yet established), the scenario code was based on the most likely extent of the species at the point of detection. For emerging species (established with limited distributions) the scenario code was based on the current extent of the species in the EU.

		Area					
		1	**2**	**3**	**4**	**5**	**6**
Populations	**A**	22	23	3	5	5	2
	B	1	11	2	0	1	4
	C	1	6	3	1	0	1
	D	0	2	0	1	0	1

Table 3. Priority matrix based on risk assessment scores (derived from horizon scanning) and scores for overall feasibility of eradication (derived from this risk management exercise). Both scores use a 5-point scale (very low to very high); however, only species with overall risk assessment scores of high and very high were included in this study (hence it was not possible for species to be placed in greyed out parts of the matrix). The matrix gives priority (for eradication) to species with the highest overall risk assessment scores and highest overall feasibility of eradication (background colour indicates priority). While focussed on prioritising eradication, the matrix can be used to consider potential priorities for prevention (new species that are high risk for which feasibility of eradication is low) and long term management (emerging species that are high risk for which feasibility of eradication is low); these priorities are marked ++ highest priority and + high priority.

Overall risk assessment score (derived from horizon scanning)	Overall feasibility of eradication (derived from this exercise)				
	Very low (1)	Low (2)	Medium (3)	High (4)	Very high (5)
Very high (5)	Medium++	Medium-high+	High	Very high	Highest
High (4)	Medium-low+	Medium	Medium-high	High	Very high
Medium (3)	Low	Medium-low	Medium	Medium-high	High
Low (2)	Very low	Low	Medium-low	Medium	Medium-high
Very low (1)	Lowest	Very low	Low	Medium-low	Medium

Figure 1. Cumulative Link Model predictions for the overall feasibility of eradication in different environments at different spatial scales. The probability of the overall feasibility of eradication being each of the five response levels very high (VH) to very low (VL) is given (on the y axis) for each combination of variables, with 95% confidence intervals. Note that colours indicate feasibility of eradication (green = higher feasibility, red = lower feasibility), these are different to those used (e.g. in Table 5.3) to indicate priority (where red = higher priority and green = lower priority).

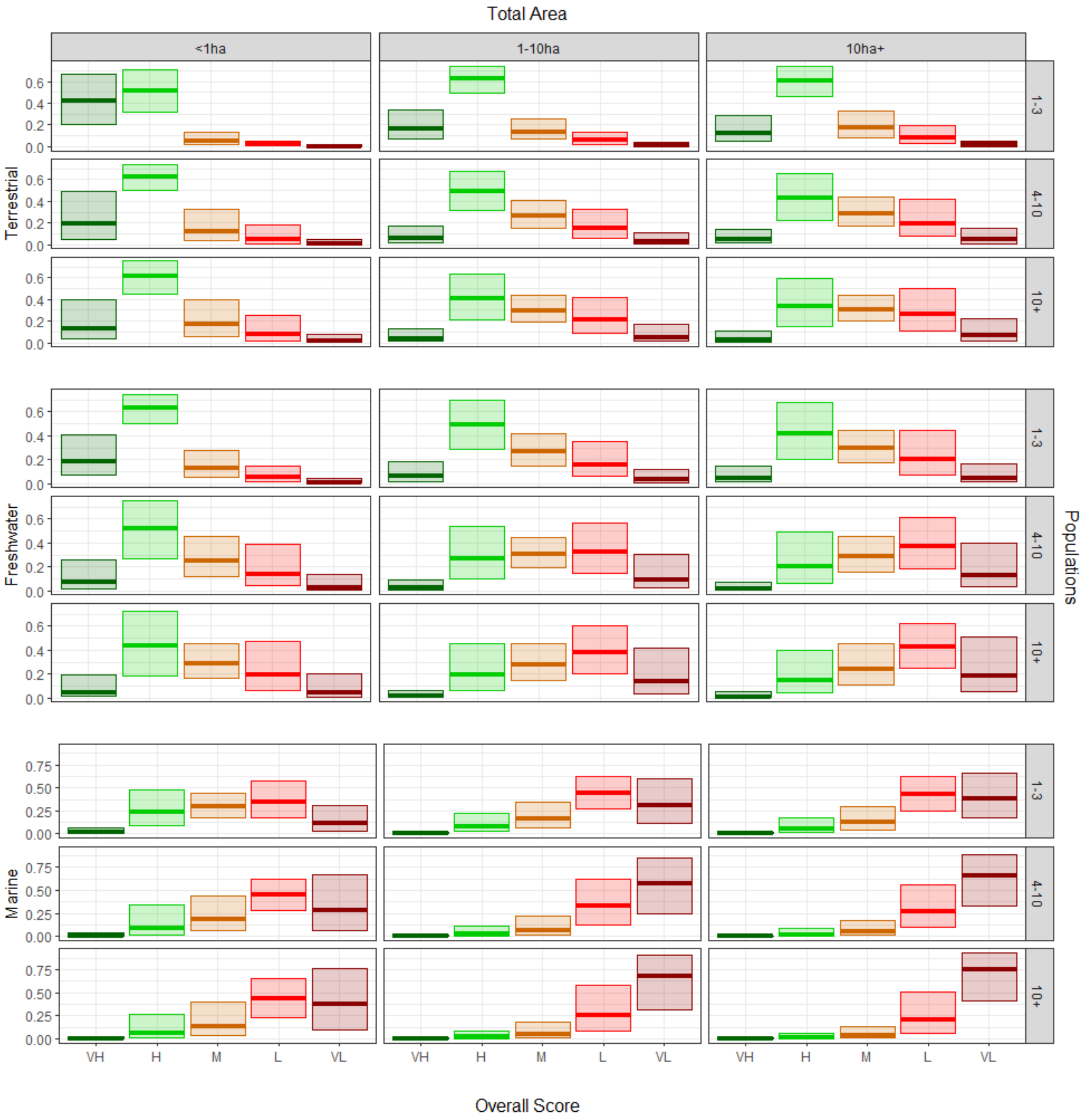


Figure 2. Counts of species within the priority matrix for (a) new and (b) emerging species. The colour of the matrix reflects priority (derived from Table 3) ranging from highest (top right) to lowest (bottom left) priority. Note that species were not included in this study with lower than high overall risk assessment scores and so no species occupy the bottom three rows of each table.

a. new species (priorities for prevention are marked highest^{++} and high^{+})

New species			Feasibility of eradication				
			VL	L	M	H	VH
			1	8	11	30	10
Risk score	VH	14	1^{++}	2^{+}	3	7	1
	H	46	0^{+}	6	8	23	9
	M	0	-	-	-	-	-
	L	0	-	-	-	-	-
	VL	0	-	-	-	-	-

Species listed in priority order:

Highest- *Orconectes rusticus*. **Very high**- *Bison bison, Channa argus, Cryptostegia grandiflora, Gambusia affinis, Lampropeltis getula, Lonicera morrowii, Micropterus dolomieu, Misgurnus mizolepis, Oreochromis aureus, Oreochromis mossambicus, Oreochromis niloticus, Pachycondyla chinensis, Rubus rosifolius, Sirex ermak, Solenopsis invicta, Trichosurus vulpecula...* **High**- *Aeolesthes sarta, Albizia lebbeck, Amynthas agrestis, Boiga irregularis, Celastrus orbiculatus, Cherax quadricarinatus, Chromolaena odorata, Chrysemys picta, Cinnamomum camphora, Clematis terniflora, Crepidula onyx, Cyprinella lutrensis, Eleutherodactylus coqui, Gymnocoronis spilanthoides, Limnoperna fortunei, Lonicera maackii, Mytilopsis sallei, Prosopis juliflora, Prunus campanulata, Pycnonotus jocosus, Rhinella marina, Solenopsis geminata, Tetropium gracilicorne, Tilapia zillii, Triadica sebifera, Vespula pensylvanica..* **Med**. **Medium-high**- *Acanthophora spicifera, Cortaderia jubata, Cynops pyrrhogaster, Hemidactylus frenatus, Lygodium japonicum, Microstegium vimineum, Solenopsis richteri, Symplegma reptans, Codium parvulum*$^{+}$, *Homarus americanus*$^{+}$. **Medium priority**- *Eleutherodactylus planirostris, Gammarus fasciatus, Lespedeza juncea, Morone americana, Perna viridis, Potamocorbula amurensis, Plotosus lineatus*$^{++}$

b. emerging species (priorities for long term management are marked highest^{++} and high^{+})

Emerging species			Feasibility of eradication				
			VL	L	M	H	VH
			7	8	8	12	0
Risk score	VH	13	3^{++}	4^{+}	2	4	0
	H	22	4^{+}	4	6	8	0
	M	0	-	-	-	-	-
	L	0	-	-	-	-	-
	VL	0	-	-	-	-	-

Species listed in priority order:

Very high - *Acridotheres tristis, Bufo mauritanicus, Nasua nasua, Pycnonotus cafer.* **High** - *Alternanthera philoxeroides, Axis axis, Botrylloides giganteum, Cherax destructor, Euonymus fortunei, Euonymus japonicus, Ligustrum sinense, Misgurnus anguillicaudatus, Rhea americana, Saperda candida.* **Medium-high** - *Andropogon virginicus, Ehrharta calycina, Fundulus heteroclitus, Hypostomus plecostomus, Marisa cornuarietis, Wedelia trilobata, Callosciurus finlaysonii*$^{+}$, *Herpestes auropunctatus*$^{+}$, *Pomacea canaliculata*$^{+}$, *Pomacea maculata*$^{+}$. **Medium** - *Acridotheres cristatellus, Charybdis japonica, Pheidole megacephala, Psittacula eupatria, Arthurdendyus triangulatus*$^{++}$, *Penaeus aztecus*$^{++}$, *Pterois miles*$^{++}$. **Medium-low** - *Ashworthius sidemi*$^{+}$, *Bellamya chinensis*$^{+}$, *Macrorhynchia philippina*$^{+}$, *Pseudonereis anomala*$^{+}$.

Table 4. Highest and very high priority species not established in Europe (n=17).

Priority	Scientific	English	RA	RM	Conf	Scen	Regions	Main method	Effect.	Pract.	Cost min (1000s)	Cost max (1000s)	Impact	Accept.	Window	Reintro.
Highest	*Orconectes rusticus*	Rusty crayfish	VH	VH	M	A1	MED, ATL, CON, STE	trapping	v. high	high	€ 1	€ 50	minimal	v. high	2m-1	high
Very high	*Bison bison*	American bison	H	VH	H	A4	CON	shooting	v. high	high	€ 1	€ 50	minimal	high	4-10	v. low
Very high	*Channa argus*	Northern snakehead	VH	H	M	A2	MAC, MED, ATL, CON, STE	electrofishing, fyke netting	v. high	v. high	€ 50	€ 200	minimal	v. high	2m-1	medium
Very high	*Cryptostegia grandiflora*	None	H	VH	H	A1	MAC, ATL, MED	mechanical, herbicide	v. high	v. high	€ 1	€ 50	minimal	v. high	1-3	high
Very high	*Gambusia affinis*	Western mosquitofish	VH	H	H	A2	MAC, MED, ATL, CON, STE	piscicide	v. high	medium	€ 50	€ 200	minor	medium	<2m	medium
Very high	*Lampropeltis getula*	Common kingsnake	VH	H	M	A4	MAC, MED	manual, trapping	high	medium	€ 200	€ 1,000	minimal	v. high	1-3	low
Very high	*Lonicera morrowii*	Morrow's honeysuckle	H	VH	M	A2	ATL, CON, MAC, MED	manual, herbicide	v. high	high	€ 1	€ 50	minor	v. high	1-3	medium
Very high	*Micropterus dolomieu*	Smallmouth bass	VH	H	M	A1	MAC, MED, ATL, CON, STE	fyke netting, electrofishing	high	high	€ 50	€ 200	minor	high	2m-1	high
Very high	*Misgurnus mizolepis*	Chinese weather loach	H	VH	H	A1	MAC, MED, ATL, CON, STE	draining, piscicide	v. high	v. high	€ 1	€ 50	minimal	v. high	2m-1	low
Very high	*Oreochromis aureus*	Blue tilapia	VH	H	H	A2	MAC, MED	netting, angling	high	high	€ 50	€ 200	minimal	high	1-3	medium
Very high	*Oreochromis mossambicus*	Mossambique tilapia	VH	H	H	A2	MAC, MED	draining, piscicide	v. high	high	€ 1	€ 50	minimal	v. high	2m-1	medium
Very high	*Oreochromis niloticus*	Nile tilapia	VH	H	H	B2	MAC, MED	draining	v. high	high	€ 1	€ 50	minimal	v. high	1-3	low
Very high	*Pachycondyla chinensis*	Asian needle ant	H	VH	M	B1	MED, ATL, CON, STE, MAC	baiting, insecticide	v. high	high	€ 1	€ 50	minimal	v. high	2m-1	medium
Very high	*Rubus rosifolius*	Roseleaf bramble	H	VH	M	A1	MAC	manual, herbicide	high	v. high	€ 1	€ 50	minimal	high	2m-1	low
Very high	*Sirex ermak*	Blue-black horntail	H	VH	H	A1	CON, STE, BOR	incineration	v. high	v. high	€ 50	€ 200	minimal	v. high	<2 m	medium
Very high	*Solenopsis invicta*	Red imported fire ant	H	VH	M	A1	MAC, MED	poison baiting	v. high	v. high	€ 1	€ 50	minimal	v. high	2m-1	high
Very high	*Trichosurus vulpecula*	Brushtail possum	H	VH	H	A4	ATL, MED, CON, MAC	trapping	v. high	v. high	€ 50	€ 200	minimal	high	1-3	v. low

Table 5. Very high and high priority species established in the EU (n=14).

Priority	Scientific	English	RA	RM	Conf	Scen	MS	Methods	Effect.	Pract.	Cost min (1000s)	Cost max (1000s)	Impact	Accept.	Window	Reintro.
Very high	*Acridotheres tristis*	Common myna	VH	H	H	A5	ES, PT	netting, trapping, shooting	high	medium	€ 200	€ 1,000	minimal	high	1-3	medium
Very high	*Bufo mauritanicus*	Berber toad	VH	H	M	A2	ES	manual capture, netting	high	medium	€ 1	€ 50	minor	v. high	1-3	low
Very high	*Nasua nasua*	Coati	VH	H	M	A4	ES	trapping, shooting	high	high	€ 200	€ 1,000	minimal	medium	1-3	low
Very high	*Pycnonotus cafer*	Red-vented bulbul	VH	H	H	A5	ES	trapping, netting	high	high	€ 50	€ 200	minimal	high	1-3	medium
High	*Alternanthera philoxeroides*	Alligator-weed	VH	M	M	C2	FR, IT	mechanical, manual	medium	high	€ 200	€ 1,000	minor	high	1-3	medium
High	*Axis axis*	Indian spotted deer	H	H	H	A6	CR	shooting, sterilization	high	high	€ 200	€ 1,000	minor	medium	4-10	low
High	*Botrylloides giganteum*	None	VH	M	M	A1	IT	wrapping structures	medium	high	€ 200	€ 1,000	minor	high	<2 m	high
High	*Cherax destructor*	Common yabby	H	H	M	A1	ES	biocontrol, trapping	high	high	€ 1	€ 50	minimal	v. high	1-3	high
High	*Euonymus fortunei*	Winter creeper	H	H	H	A2	FR	herbicide	high	low	€ 50	€ 200	minor	high	1-3	high
High	*Euonymus japonicus*	Japanese spindle	H	H	M	B2	UK	grubbing, mechanical, herbicide	high	high	€ 1	€ 50	minor	v. high	1-3	high
High	*Ligustrum sinense*	Chinese privet	H	H	M	B2	FR	grubbing, mechanical, herbicide	high	high	€ 1	€ 50	moderate	v. high	1-3	medium
High	*Misgurnus anguillicaudatus*	Oriental weatherfish	H	H	H	C4	NL, DE, ES, IT	electrofishing, piscicide, fyke netting	v. high	medium	€ 200	€ 1,000	moderate	low	1-3	medium
High	*Rhea americana*	Greater rhea	H	H	M	A5	DE	shooting, and other methods	v. high	high	€ 200	€ 1,000	minor	medium	1-3	medium
High	*Saperda candida*	Apple tree borer	H	H	H	B2	DE	manual destruction, felling of trees	high	high	€ 1	€ 50	minor	high	1-3	medium

Supplementary Information

S1. The full modified scheme is available as supplementary information

S2. Factor plot

S3. nMDS

S4. Pairwise separation of thresholds

S5. Cumulative link model to examine the relationship between environment and extent

S6. Risk assessment, risk management and priority scores for new IAS

S7. Risk assessment, risk management and priority scores for all emerging IAS

Supplementary Information 1.

Guidance for the full modified NNRM scheme.

1. Background

This guidance is provided to assess management options for:

- Non-native species already established in the EU, where options for eradication are being considered.
- Non-native species not yet established in the EU, where options for eradication following detection in the wild are being considered.

Aspects of risk management not related to eradication, i.e. prevention and long term management, are not part of this exercise.

The process for assessing risk management options is set out below and should be read in conjunction with the template at Annex 1.

2. Preliminary sections

Define the risk management area. For this exercise the risk management area is the European Union, excluding Outermost Territories.

State the objective of the assessment. The objective is predefined as 'the eradication (defined as the complete removal of a species from a defined geographic area[1]) of the target organism from the risk management area'.

Define the target organism. The target organism can be any taxon but must be clearly defined.

Record the name(s) of assessors, date and version number of the assessment.

3. Assessment

Step 1 - Define the Scenario

The first step is to describe the extent of the species either based on its current distribution (if already established) or based on its most likely situation at the point it is discovered (for species not currently established).

For species that are already present in the wild - the scenario should be the current situation, i.e. the current level of establishment (estimated if necessary / existing information is weak).

[1] Genovesi, P. (2000) Guidelines for eradication of terrestrial vertebrates: a European contribution to the invasive alien species issue. Council of Europe, Strasbourg, tpvs65e-2000, 61pp,

For species not yet present in the wild - the scenario should be the most likely situation at the point the species is detected in the wild (based on current surveillance).

In defining the scenario you should consider (but only include if relevant):

- How widespread the species is (or will be at the point of detection) in the EU.
- The types of habitats / environments in which the species is (or will be) present.
- How many spatially distinct populations there are (or will be).
- What the size of the total population is (or will be).

For example:

- *Trichosurus vulpecula* (Brushtail Possum) is not currently established in the EU. At the point of the detection, the most likely scenario is a single population in broadleaved woodland spread over 1-10km^2 and comprising 10-50 individuals. This could occur in any of the temperate regions of the EU.

A code should be provided for the scenario based on the number of discrete populations and total combined area of those populations using the table at Annex 2.

Step 2 – Define the eradication Strategy

The assessor should briefly describe a realistic strategy that could be used to eradicate the species <u>entirely from the EU</u>. This could include multiple methods (e.g. trapping, chemical use and mechanical removal); it should also include other elements, such as surveys, logistics and monitoring, if they are required in order to achieve eradication.

The strategy that is most likely to be successful should be described. If no realistic strategy can be envisaged then it can still be useful to quickly assess extreme strategies.

The rest of the assessment (i.e. effectiveness, cost, etc.) will be based on the eradication strategy described here.

For example:

- The strategy to eradicate *Trichosurus vulpecula* (Brushtail Possum) would be trapping. Initial surveillance would be carried out in the 10km^2 area and a surrounding 2km buffer zone, including the use of camera traps / trained dogs / hair traps (?). Trapping would include live cage traps and kill traps (some of which may be at height).

Step 3 – Scoring the eradication strategy

The eradication strategy should be assessed using the criteria defined under the headings below (3a to 3d).

The response score is a 5 point scale from 1-5. In all cases 1 is the least favourable and 5 the most. For example, a very effective eradication strategy scores 5, a very ineffective strategy scores 1; whereas a very inexpensive strategy (i.e. the cost favours taking action) scores 5, a very expensive one scores 1.

Table 1. Assessment criteria for response scores.

Criteria	Response Score				
	1	2	3	4	5
Effectiveness	Very ineffective	Ineffective	Moderate effectiveness	Effective	Very effective
Practicality	Very impractical	Impractical	Moderate practicality	Practical	Very practical
Cost	>€10M	€1-10M	€200k-1M	€50-200k	<€50k
Negative impact	Massive	Major	Moderate	Minor	Minimal
Acceptability	Very unacceptable	Unacceptable	Moderate acceptability	Acceptable	Very acceptable
Window of opportunity	< 2 months	2 months - 1 year	1 – 3 years	4-10 years	>10 years
Likelihood of reinvasion	Very likely	Likely	Moderate likelihood	Unlikely	Very unlikely
Conclusion (overall feasibility of eradication)	Very low	Low	Medium	High	Very high

A confidence rating should be provided for every response score. Confidence is recorded on a 3 point scale: 1 (low), 2 (medium), 3 (high). Even where evidence is lacking, assessors should make best guess judgements and use the confidence rating score to reflect uncertainty.

Confidence Score	Description
High	>80% chance of assessment being correct
Medium	35-80% chance of assessment being correct
Low	<35% chance of assessment being correct

Step 3a - Effectiveness

This part of the assessment scores how effective the defined eradication strategy would be regardless of other issues, such as the practicality of deploying methods, costs, acceptability of methods, etc. which are taken into account elsewhere. For example, the eradication strategy for a non-native fish in a river could be to flood it with the pesticide rotenone – this would likely score ‘very effective’ despite low scores associated with practicality, impact and acceptability.

Points to consider:

- How effective has this approach proven to be in the past or in an analogous situation?

- How effective is the approach despite the biology / behaviour of the target organism?

Scoring scale:

- 5 – very effective
- 4 – effective
- 3 – moderate effectiveness
- 2 – infective
- 1 – very infective

Step 3b - Practicality

How practical is it to deploy the described strategy? In particular, consider barriers that might prevent the use of the strategy such as issues gaining access to relevant areas, obtaining appropriate equipment, skilled staff, chemicals, etc. If there are any legal barriers to undertaking the work these should be assessed here.

Points to consider:

- How available are the methods in the EU?
- How accessible are the areas required to deploy the eradication strategy?
- How easy would it be to obtain relevant licences or other approvals / permissions (e.g. access permission) to undertake the approach?
- How easy would it be to overcome legal barriers?
- How safe are the methods used in this approach (are there health and safety barriers)?

Scoring scale:

- 5 – very practical
- 4 – practical
- 3 – moderate practicality
- 2 – impractical
- 1 – very impractical

Step 3c - Cost

Cost relates to the total direct cost of eradicating the species from the EU using the defined eradication strategy. Total cost includes the cost of staff, resources, materials, etc. over the entire time period involved in the eradication and any required post eradication surveillance and follow-up. Note indirect costs (e.g. loss of business) are considered an impact and not recorded here.

In your comment, indicate the period over which costs would be occurred (i.e. number of years) and, if possible, indicate whether the cost would be evenly spread, frontloaded or back loaded.

Scoring scale:

- 5 - minimal - <€50k
- 4 - minor - €50-200k
- 3 - moderate - €200k-1M
- 2 - major - €1-10M
- 1 - massive - >€10M

Step 3d - Impact

Impact relates to the impact of the eradication strategy itself. It is important to note that any indirect economic impacts (i.e. economic consequences of the eradication strategy rather than the cost of the strategy itself) are recorded here and not under ‘cost’.

Points to consider:

- How significant is the environmental harm caused by this approach?
- How significant is the economic harm caused by this approach?

  Examples of economic harm might include: reduction in the ability to trade or do business as a result of the management method; loss of earnings; reduction in tourism; reduction in house prices; etc.

- How significant is the social harm, including to human health, caused by this approach (note that this is different from acceptability below)?

  Examples of social harm might be a reduction in a person’s use or enjoyment (e.g. preventing them walking in a woodland or fishing in a river), disruptions of communities, etc.

Scoring scale:

- 5 - minimal

- 4 - minor
- 3 - moderate
- 2 - major
- 1 - massive

Step 3e - Acceptability

Acceptability relates to significant issues that could arise as a result of disapproval or resistance from individuals, groups or sectors. This does not include regulatory or legislative barriers which are considered under practicality.

- How acceptable is the approach likely to be based on environmental / animal welfare grounds?

  Note this question relates to likely criticism / resistance that the approach would meet based on environmental / animal welfare grounds.

- How acceptable is the approach likely to be to the general public?
- How acceptable is the approach likely to be to other stakeholders?

Scoring scale:

- 5 – very acceptable
- 4 – acceptable
- 3 – moderate acceptability
- 2 – unacceptable
- 1 – very unacceptable

Step 4 – Assessing the window of opportunity

The window of opportunity relates to how quickly the species will spread beyond the point that eradication, using the defined strategy, would be effective. It is linked to the mechanism and rate of spread, which is considered during the risk assessment.

Scoring scale:

- 5 - very long (10+ years)
- 4 - long (4-10 years)

- 3 - moderate (1 – 3 years)
- 2 - short (2 months - 1 year)
- 1 - very short (< 2 months)

Step 5 – Assessing the likelihood of re-introduction

Assuming the eradication is successful, i.e. there are no wild populations of the species left, how likely is it that re-introduction will occur? Note: unless the eradication strategy has deliberately targeted populations in containment or otherwise not in the wild (i.e. in gardens, zoos, etc.) introduction from these should be considered part of re-introduction.

Scoring scale:

- 5 – very unlikely
- 4 – unlikely
- 3 – moderate likelihood
- 2 – likely
- 1 – very likely

Step 6 – Final risk management score

The final risk management score is the overall conclusion of the assessment taking into account all factors (i.e. 3a – 5). Assessors should provide a score they consider appropriate, taking other scores into account (but note the overall score is not necessarily the mean of other scores).

Scoring scale:

- 5 – very high
- 4 – high
- 3 – moderate
- 2 – low
- 1 – very low

Annex 1. Template for Non-native Risk Management Assessment

Risk management area:	
Objective:	
Organism name:	
Assessor name(s):	
Date / version:	

Title	Response	Confidence	Justification
1. Define the scenario	*Input scenario and scenario code*		
2. Define the eradication strategy	*Input eradication strategy*		
3a. How effective is the strategy?	5 - V EFFECTIVE 4 – EFFECTIVE 3 – MODERATE 2 – INEFFECTIVE 1 - V INEFFECTIVE	3 – HIGH 2 – MED 1 – LOW	
3b. How practical is the strategy?	5 - V PRACTICAL 4 – PRACTICAL 3 – MODERATE 2 – IMPRACTICAL 1 – V IMPRACTICAL	3 – HIGH 2 – MED 1 – LOW	
3c. How expensive is the strategy?	5 (<£50K) 4 (£50-200K) 3 (£200K-1M) 2 (1-10M) 1 (> £10M)	3 – HIGH 2 – MED 1 – LOW	
3d. How much negative impact would the strategy have?	5 – MINIMAL 4 – MINOR 3 – MODERATE 2 – MAJOR 1 – MASSIVE	3 – HIGH 2 – MED 1 – LOW	
3e. How acceptable is the strategy?	5 - V ACCEPTABLE 4 – ACCEPTABLE 3 – MODERATE 2 – UNACCEPTABLE 1 - V UNACCEPTABLE	3 – HIGH 2 – MED 1 – LOW	
4. What is the window of opportunity for implementing the strategy?	5 (10+ YRS) 4 (4-10 YRS) 3 (1 – 3 YRS) 2 (2 MTHS - 1 YR) 1 (< 2 MTHS)	3 – HIGH 2 – MED 1 – LOW	
5. What is the likelihood of reinvasion?	5 – V UNLIKELY 4 – UNLIKELY 3 – MODERATE 2 – LIKELY 1 – V LIKELY	3 – HIGH 2 – MED 1 – LOW	
6. Conclusion (overall feasibility of eradication)	5 – V HIGH 4 – HIGH 3 – MEDIUM 2 – LOW 1 – V LOW	3 – HIGH 2 – MED 1 – LOW	

Annex 2. Table for codifying the scenario based on number of discrete populations and total area

Identify one box in the table to indicate the likely number of sites containing the species and the combined area of these populations. Populations are considered discrete if they would be unlikely to recolonise from other areas after removal. The total area is that from which the species would need to be removed, i.e. for three populations of a species each covering 10ha and each 100km apart, the total area is 30ha, not 100km+.

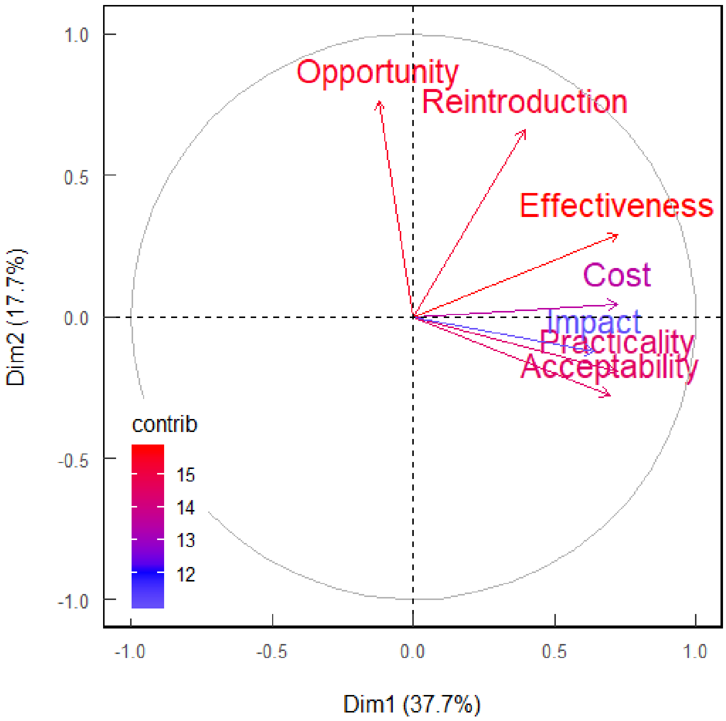
		Total combined area of populations					
		<1ha	1-10ha	10ha-1km2	1-10km2	10-100km2	>100km2
Number of discrete populations	1-3	A1 1-3 discrete populations estimated covering a total area of <1ha	A2 1-3 discrete populations estimated covering a total area of 1-10ha	A3 1-3 discrete populations estimated covering a total area of 10ha-1km2	A4 1-3 discrete populations estimated covering a total area of 1-10km2	A5 1-3 discrete populations estimated covering an area of 10-100km2	A6 1-3 discrete populations estimated covering an area of >100km2
	4-10	B1 4-10 discrete populations estimated covering a total area of <1ha	B2 4-10 discrete populations estimated covering a total area of 1-10ha	B3 4-10 discrete populations estimated covering a total area of 10ha-1km2	B4 4-10 discrete populations estimated covering a total area of 1-10km2	B5 4-10 discrete populations estimated covering a total area of 10-100km2	B6 4-10 discrete populations estimated covering a total area of >100km2
	10-50	C1 10-50 discrete populations estimated covering a total area of <1ha	C2 10-50 discrete populations estimated covering a total area of 1-10ha	C3 10-50 discrete populations estimated covering a total area of 10ha-1km2	C4 10-50 discrete populations estimated covering a total area of 1-10km2	C5 10-50 discrete populations estimated covering a total area of 10-100km2	C6 10-50 discrete populations estimated covering a total area of >100km2
	+50	D1 50+ discrete populations estimated covering a total area of <1ha	D2 50+ discrete populations estimated covering a total area of 1-10ha	D3 50+ discrete populations estimated covering a total area of 10ha-1km2	D4 50+ discrete populations estimated covering a total area of 1-10km2	D5 50+ discrete populations estimated covering a total area of 10-100km2	D6 50+ discrete populations estimated covering a total area of >100km2

Supplementary Information 2.

nMDS (non-metric Multidimensional scaling) ordination of all species based on the component scores (effectiveness, practicality, cost, impact, acceptability, window of opportunity and likelihood of reintroduction), coloured based on the score for overall feasibility of eradication. The axes of this plot are the same as those in the factor analysis above (Appendix G), with Dim 1 correlated with effectiveness, practicality, cost, impact and acceptability, while Dim 2 is more closely correlated with window of opportunity and likelihood of reinvasion. The coloured ellipses are a visual aid to show the mean (large symbol) and variation (the scaled shape and size of the ellipse) of the score for overall feasibility of eradication. The score for overall feasibility of eradication aligns in sequence with Dim1 but with some overlap, or species out of sequence, particularly between scores 2, 3 and 4.

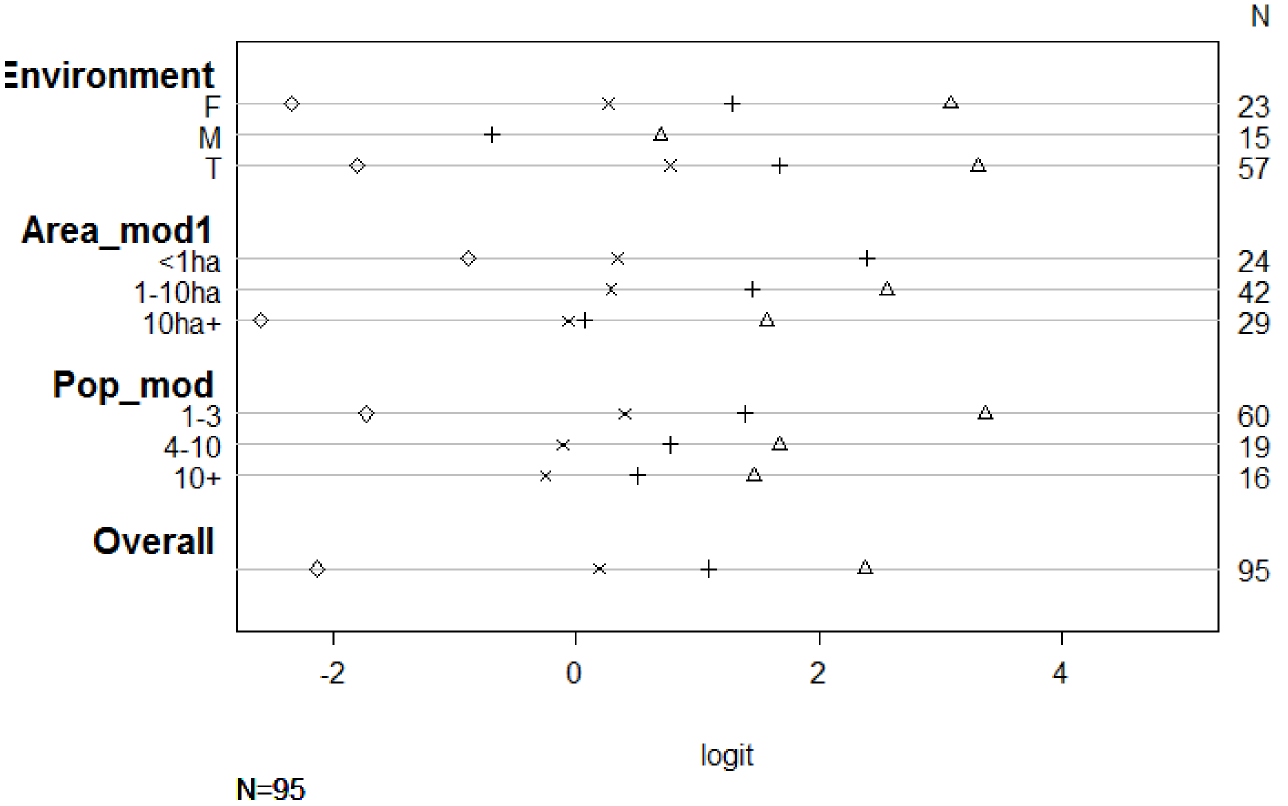
Supplementary Information 3.

Factor plot of risk management components. Cost, Impact, Practicality and Acceptability were all highly correlated and were the main driver of dimension 1 (37.8% variation) but these components did not correlate with Likelihood of reintroduction. Window of Opportunity had the highest correlation with Dimension 2 (17.3% variability).



Supplementary Information 4.

Pairwise separation of thresholds of each ordinal scale for each risk management covariate.



Supplementary Information 5.

Cumulative link model summary for the overall feasibility of eradication score predicted by environment, total area and number of populations

link	threshold	nobs	logLik	AIC	niter	max.grad	cond.H
logit	flexible	95	-111.45	242.90	6(0)	6.67e-11	6.3e+01

Coefficients:

Covariate	Estimate	Std. Error	z value	Pr(>|z|)
EnvironmentM	-2.5875	0.6801	-3.805	0. 000142 ***
EnvironmentT	1.1538	0.5232	2.205	0.027436 *
Area_mod11-10ha	-1.2732	0.5574	-2.284	0.022348 *
Area_mod110ha+	-1.6272	0.6051	-2.689	0.007166 **
Pop_mod4-10	-1.1217	0.5465	-2.052	0.040122 *
Pop_mod10+	-1.5621	0.5885	-2.654	0.007944 **

Supplementary Information 6.

Management priorities for new (i.e. not established) IAS in the EU.

Management priorities for new (i.e. not established) IAS in the EU (n=60): highest (1), very high (16), high (26), med-high (10), medium (7), med-low (0). Potential priorities for prevention based on high risk and low feasibility of eradication are denoted $^{++}$highest and $^{+}$very high priority. F^1 = scenario based on species in still (or slow flowing) freshwater; F^2 = scenario based on species in flowing freshwater.

Scientific Name	**English Name**	**Environment**	**Group**	**Scenario code**	**Risk category**	**Feasibility of eradication**	**Priority**
Orconectes rusticus	Rusty crayfish	F^1	Crustacean	A1	VH	VH	Highest
Bison bison	American bison	T	Mammal	A4	H	VH	Very high
Channa argus	Northern snakehead	F^2	Fish	A2	VH	H	Very high
Cryptostegia grandiflora	None	T	Plant	A1	H	VH	Very high
Gambusia affinis	Western mosquitofish	F^1	Fish	A2	VH	H	Very high
Lampropeltis getula	Common Kingsnake	T	Reptile	A4	VH	H	Very high
Lonicera morrowii	Morrow's Honeysuckle	T	Plant	A2	H	VH	Very high
Micropterus dolomieu	Smallmouth bass	F^1	Fish	A1	VH	H	Very high
Misgurnus mizolepis	Chinese weather loach	F^1	Fish	A1	H	VH	Very high
Oreochromis aureus	Blue tilapia	F^1	Fish	A2	VH	H	Very high
Oreochromis mossambicus	Mossambique tilapia	F^1	Fish	A2	VH	H	Very high
Oreochromis niloticus	Nile tilapia	F^1	Fish	B2	VH	H	Very high
Pachycondyla chinensis	Asian Needle Ant	T	Insect	B1	H	VH	Very high
Rubus rosifolius	Roseleaf Bramble	T	Plant	A1	H	VH	Very high
Sirex ermak	Blue-black Horntail	T	Insect	A1	H	VH	Very high
Solenopsis Invicta	Red Imported Fire Ant	T	Insect	A1	H	VH	Very high
Trichosurus Vulpecula	Brushtail Possum	T	Mammal	A4	H	VH	Very high
Aeolesthes sarta	City Longhorn Beetle	T	Insect	C3	H	H	High
Albizia lebbeck	Indian Siris	T	Plant	B2	H	H	High
Amynthas agrestis	Crazy snake worm	T	Annelid	C1	H	H	High
Boiga irregularis	Brown tree snake	T	Reptile	A2	H	H	High
Celastrus orbiculatus	Oriental Bittersweet	T	Plant	C3	H	H	High
Cherax quadricarinatus	Redclaw crayfish	F^1	Crustacean	A1	H	H	High
Chromolaena odorata	None	T	Plant	A2	H	H	High

Chrysemys picta	Painted turtle	T	Reptile	B3	H	H	High
Cinnamomum camphora	Camphor Tree	T	Plant	A2	H	H	High
Clematis terniflora	Leather Leaf Clematis	T	Plant	B2	H	H	High
Crepidula onyx	Onyx slippersnail	M	Mollusc	A2	VH	M	High
Cyprinella lutrensis	Red shiner	F^2	Fish	A1	H	H	High
Eleutherodactylus coqui	Common coquí	T	Amphibian	A2	H	H	High
Gymnocoronis spilanthoides	Senegal tea	T	Plant	A2	H	H	High
Limnoperna fortunei	Golden mussel	$F^?$	Mollusc	A1	VH	M	High
Lonicera maackii	Amur Honeysuckle	T	Plant	A2	H	H	High
Mytilopsis sallei	Black striped mussel	M	Mollusc	A1	VH	M	High
Prosopis juliflora	Prosopis	T	Plant	C2	H	H	High
Prunus campanulata	Bell flower cherry	T	Plant	A2	H	H	High
Pycnonotus jocosus	Red-whiskered Bulbul	T	Bird	A5	H	H	High
Rhinella marina	Cane toad	T	Amphibian	A4	H	H	High
Solenopsis geminata	Tropical fire ant	T	Insect	A1	H	H	High
Tetropium gracilicorne	Fine-horned spruce beetle	T	Insect	C2	H	H	High
Tilapia zillii	Redbelly tilapia	$F^?$	Fish	B2	H	H	High
Triadica sebifera	Chinese Tallowtree	T	Plant	A1	H	H	High
Vespula pensylvanica	Western yellowjacket	T	Insect	C2	H	H	High
Acanthophora spicifera	a red alga	M	Alga	A1	H	M	Med-high
Cortaderia jubata	None	T	Plant	A2	H	M	Med-high
Cynops pyrrhogaster	Fire-bellied salamander	T	Amphibian	A2	H	M	Med-high
Hemidactylus frenatus	House gecko	T	Reptile	A1	H	M	Med-high
Lygodium japonicum	Japanese Climbing Fern	T	Plant	A2	H	M	Med-high
Microstegium vimineum	Nepalese Browntop	T	Plant	B2	H	M	Med-high
Solenopsis richteri	Black Imported Fire Ant	T	Insect	D2	H	M	Med-high
Symplegma reptans	a tunicate	M	Tunicate	A1	H	M	Med-high
Codium parvulum	a green alga	M	Alga	A2	VH	L	Med-high$^+$
Homarus americanus	American Lobster	M	Crustacean	A3	VH	L	Med-high$^+$
Eleutherodactylus planirostris	Greenhouse frog	T	Amphibian	A2	H	L	Medium
Gammarus fasciatus	Freshwater shrimp	F^1	Crustacean	A1	H	L	Medium
Lespedeza juncea ssp. sericea	None	T	Plant	C2	H	L	Medium
Morone americana	White perch	F^2	Fish	A1	H	L	Medium
Perna viridis	Asian Green mussel	M	Mollusc	A2	H	L	Medium
Potamocorbula amurensis	Asian basket clam	M	Mollusc	A3	H	L	Medium
Plotosus lineatus	Striped eel catfish	M	Fish	A2	VH	VL	Medium^{++}

Supplementary Information 7.

Management priorities for emerging (i.e. established with limited distributions) IAS in the EU.

Priorities for emerging (i.e. established with limited distributions) IAS in the EU (n=35): highest (0), very high (4), high (10), med-high (10), medium (7), med-low (4). Potential priorities for long term management based on high risk and low feasibility of eradication are denoted ++highest and +very high priority. F^1 = scenario based on species in still (or slow flowing) freshwater; F^2 = scenario based on species in flowing freshwater.

Scientific Name	English Name	Environment	Group	Scenario code	Risk category	Feasibility of eradication	Priority
Acridotheres tristis	Common myna	T	Bird	A5	VH	H	Very high
Bufo mauritanicus	Berber toad	T	Amphibian	A2	VH	H	Very high
Nasua nasua	Coati	T	Mammal	A4	VH	H	Very high
Pycnonotus cafer	Red-vented Bulbul	T	Bird	A5	VH	H	Very high
Alternanthera philoxeroides	Alligator-weed	F	Plant	C2	VH	M	High
Axis axis	Indian spotted deer	T	Mammal	A6	H	H	High
Botrylloides giganteum	a tunicate	M	Tunicate	A1	VH	M	High
Cherax destructor	Common yabby	F^1	Crustacean	A1	H	H	High
Euonymus fortunei	Winter Creeper	T	Plant	A2	H	H	High
Euonymus japonicus	Japanese spindle	T	Plant	B2	H	H	High
Ligustrum sinense	Chinese Privet	T	Plant	B2	H	H	High
Misgurnus anguillicaudatus	Oriental weatherfish	F^2	Fish	C4	H	H	High
Rhea americana	Greater rhea	T	Bird	A5	H	H	High
Saperda candida	Apple Tree Borer	T	Insect	B2	H	H	High
Andropogon virginicus	Broom-sedge	T	Plant	C2	H	M	Med-high
Ehrharta calycina	Perennial Veldtgrass	T	Plant	B2	H	M	Med-high
Fundulus heteroclitus	Mummichog	F^2	Fish	B3	H	M	Med-high
Hypostomus plecostomus	Suckermouth catfish	F^2	Fish	A1	H	M	Med-high
Marisa cornuarietis	Giant ramshorn snail	F^2	Mollusc	A1	H	M	Med-high
Wedelia trilobata	Wedelia	T	Plant	B2	H	M	Med-high
Callosciurus finlaysonii	Finlayson's squirrel	T	Mammal	A6	VH	L	Med-high+
Herpestes auropunctatus	Small Asian mongoose	T	Mammal	B6	VH	L	Med-high+
Pomacea canaliculata	Golden apple snail	F^2	Mollusc	A2	VH	L	Med-high+

Pomacea maculata	Giant apple snail	F[1]	Mollusc	C3	VH	L	Med-high[+]
Acridotheres cristatellus	Crested Myna	T	Bird	B6	H	L	Medium
Charybdis japonica	Asian paddle crab	M	Decapod	A3	H	L	Medium
Pheidole megacephala	Big-headed Ant	T	Insect	D4	H	L	Medium
Psittacula eupatria	Alexandrine parakeet	T	Bird	B5	H	L	Medium
Arthurdendyus triangulatus	New Zealand flatworm	T	Platyhelminth	D2	VH	VL	Medium[++]
Penaeus aztecus	Northern brown shrimp	M	Crustacean	B6	VH	VL	Medium[++]
Pterois miles	Devil firefish, Lion fish	M	Fish	C6	VH	VL	Medium[++]
Ashworthius sidemi	None	T	Nematode	D6	H	VL	Med-low[+]
Bellamya chinensis	Chinese mystery snail	F[2]	Mollusc	B2	H	VL	Med-low[+]
Macrorhynchia philippina	White stinger	M	Hydroid	B6	H	VL	Med-low[+]
Pseudonereis anomala	a polychaete	M	Polychaete	A5	H	VL	Med-low[+]